Negative-Refractive-Index Transmission-Line Metamaterials: Fundamentals and Applications

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Recently there has been renewed interest in artificial materials with electromagnetic properties that cannot be found in nature. Therefore these materials are referred to as "metamaterials" ("meta" means "beyond" in Greek). This tutorial mainly addresses metamaterials that are characterized by a negative refractive index. The feasibility of media that simultaneously exhibit negative permittivity and negative permeability, hence a negative refractive index, has been known since the sixties. However it is only recently that people invented ways to realize them. In such negative-refractive-index (NRI) or "left-handed" metamaterials, waves can be thought of as propagating backward instead of forward. When interfaced with conventional dielectric materials, incident waves become focused on a point instead of diverging outwards, thus suggesting the implementation of lenses with flat surfaces.

In this presentation, first the fundamental properties of NRI metamaterials will be reviewed. Subsequently, it will be demonstrated that NRI metamaterials can be synthesized using planar networks of loaded transmission lines (TL). The resulting NRI-TL metamaterials can be easily constructed using embedded capacitors and inductors, and they offer wide operating bandwidths and low insertion losses. It will be shown that the reason for these benefits is the tight coupling between the constituent adjacent resonators. The theoretical and experimental extension of these media to 3D isotropic and related volumetric NRI-TL metamaterials will be discussed. Based on this approach, microwave NRI metamaterial lenses that can resolve details beyond the classical diffraction limit will be presented. Recent results in achieving sub-wavelength focusing in free-space will also be demonstrated. Moreover, a number of useful antenna and microwave devices (passive and active in CMOS), enabled by such NRI-TL metamaterials will be described. These enabling materials and devices can find applications in diverse areas such as emerging broadband wireless communications, defence, medical imaging and sensing, photolithography and microscopy.